Beam Diagnostics and Instrumentation

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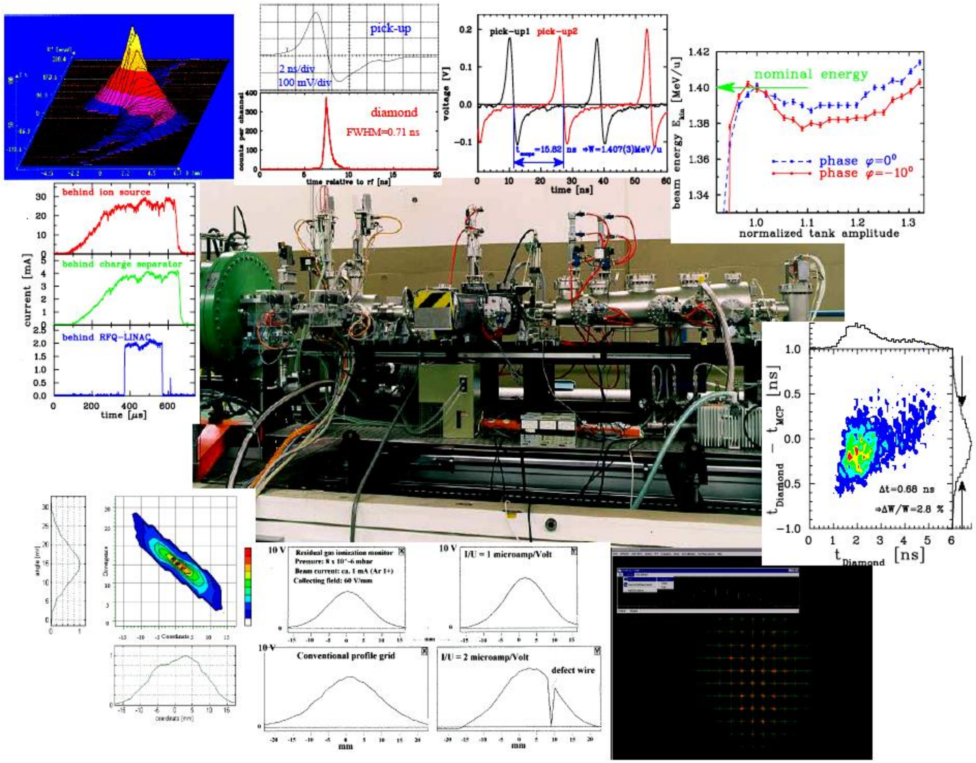


European Scientific Institute

Joint Universities Accelerator School

Demands on Beam Diagnostics

Diagnostics is the 'sensory organs' for the beam.

It deals with *real* beams in *real* technical installations including all imperfections.

Three types of demands lead to different installations:

- Quick, non-destructive measurements leading to a single number or simple plots

  Used as a check for online information. Reliable technologies have to be used

  Example: Current measurement by transformers
- Instruments for daily check, malfunction diagnosis and wanted parameter variation

  Example: Profile measurement, in many cases 'intercepting' i.e. destructive to the beam
- Complex instruments for severe malfunctions, accelerator commissioning & development

  The instrumentation might be destructive and complex

  Example: Emittance determination

General usage of beam instrumentation:

- Monitoring of beam parameters for operation, beam alignment, acc. development.....
- Instruments for automatic, active beam control

  Example: Closed orbit feedback using position measurement by BPMs

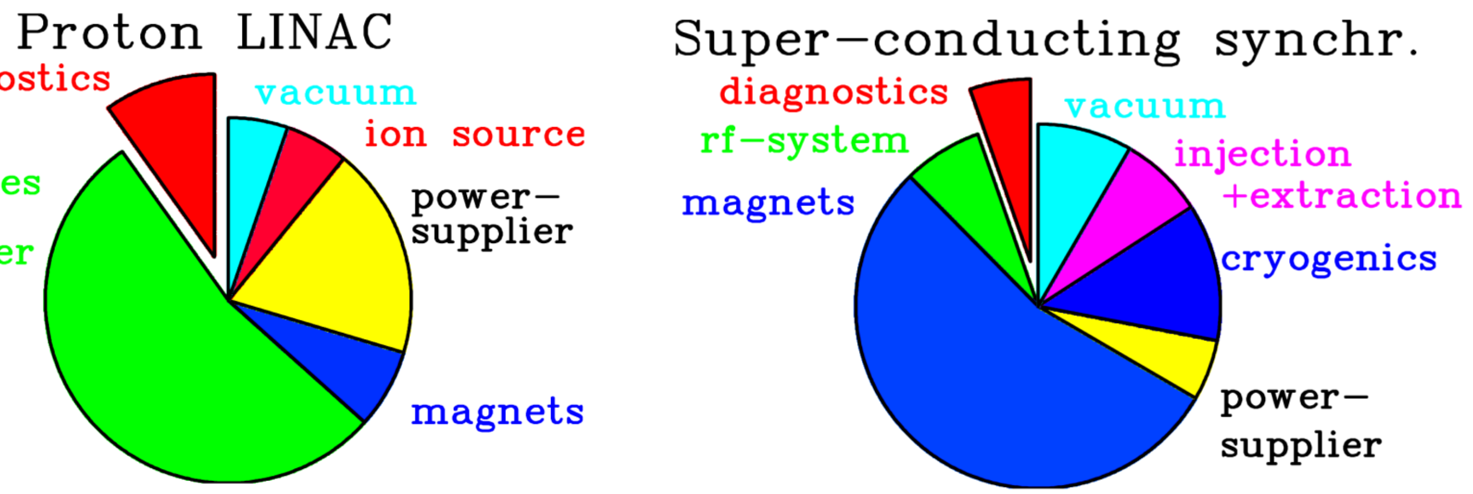
Non-destructive ('non-intercepting') methods are preferred:

- The beam is not influenced
- The instrument is not destroyed

The cost of diagnostics is about 3 to 10 % of the total facility cost:

- ≈ 3 % for large accelerators ***or*** accelerators with standard technologies
- ≈ 10 % for versatile accelerators ***or*** novel accelerators and technologies.

Cost Examples:



The amount of man-power is about 10 to 20 %:

- Very different physics and technologies are applied
- Technologies have to be up-graded, e.g. data acquisition and analysis
- Accelerator improvement calls for new diagnostic concepts.

Beam Quantities and their Diagnostics I

LINAC & transport lines: single pass ↔ **Synchrotron:** multi pass

Electrons: always relativistic ↔ **Protons/Ions:** non-relativistic for E_{kin} < 1 GeV/u

Depending on application: low current ↔ high current

Overview of the most commonly used systems:

Beam quantity		Transfer line	Synchrotron
Current *I*	*General*	**Transformer, dc & ac**	**Transformer, dc & ac**
		Faraday Cup	
	Special	**Particle Detectors**	Pick-up Signal (relative)
Profile x_{width}	*General*	**Screens, SEM-Grids**	**Ionization Profile Monitor**
		Wire Scanners, OTR Screen	**Wire Scanner,**
			Synchrotron Light Monitor
	Special	MWPC, **Fluorescence Light**	
Position x_{cm}	*General*	**Pick-up (BPM)**	**Pick-up (BPM)**
	Special	Using position measurement	
Transverse Emittance ε_{trans}	*General*	**Slit-grid**	**Ionization Profile Monitor**
		Quadrupole Variation	**Wire Scanner**
	Special	Pepper-Pot	Transverse Schottky

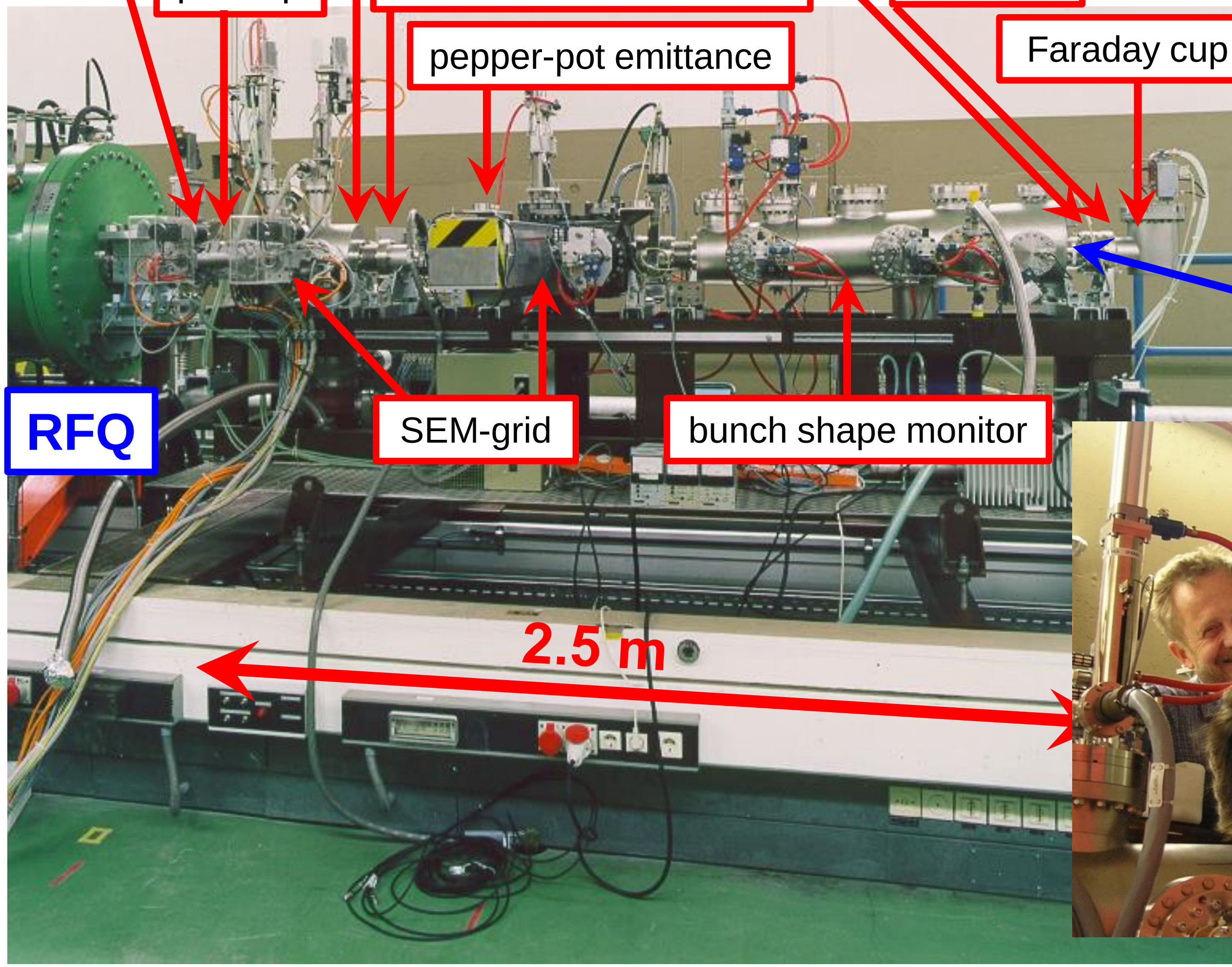
Beam Quantities and their Diagnostics II

Beam quantity		Transfer line	Synchrotron
Bunch Length $\Delta\varphi$	*General* *Special*	**Pick-up** **Secondary electrons arrival** **Electro-optical laser mod.**	**Pick-up** Wall Current Monitor **Streak Camera** **Electro-optical laser mod.**
Momentum p **and Momentum Spread** $\Delta p/p$	*General* *Special*	**Pick-ups (Time-of-Flight)** Magnetic Spectrometer	**Pick-up (e.g. tomography)** Schottky Noise Spectrum
Longitudinal Emittance ε_{long}	*General* *Special*	**Buncher variation** Magnetic Spectrometer	 **Pick-up & tomography**
Tune and Chromaticity Q, ξ	*General* *Special*	--- ---	**Exciter + Pick-up** Transverse Schottky Spectrum
Beam Loss r_{loss}	*General*	**Particle Detectors**	
Polarization P	*General* *Special*	Particle Detectors Laser Scattering (Compton scattering)	
Luminosity L	*General*	Particle Detectors	

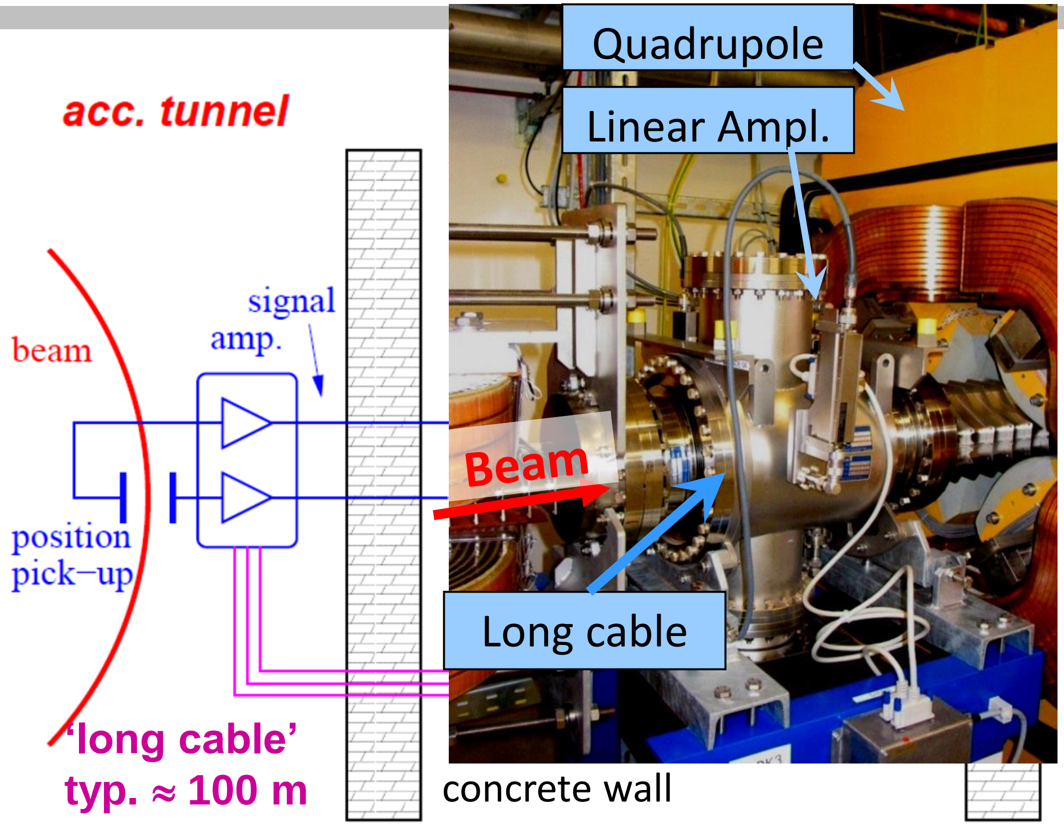
- Destructive and non-destructive devices depending on the beam parameter.
- Different techniques for the same quantity ↔ Same technique for the different quantities.

Remark: In most cases no diagnostics device installed inside the rf-cavities (except cyclotron)

Example: Diagnostics Bench for the Commissioning of an RFQ



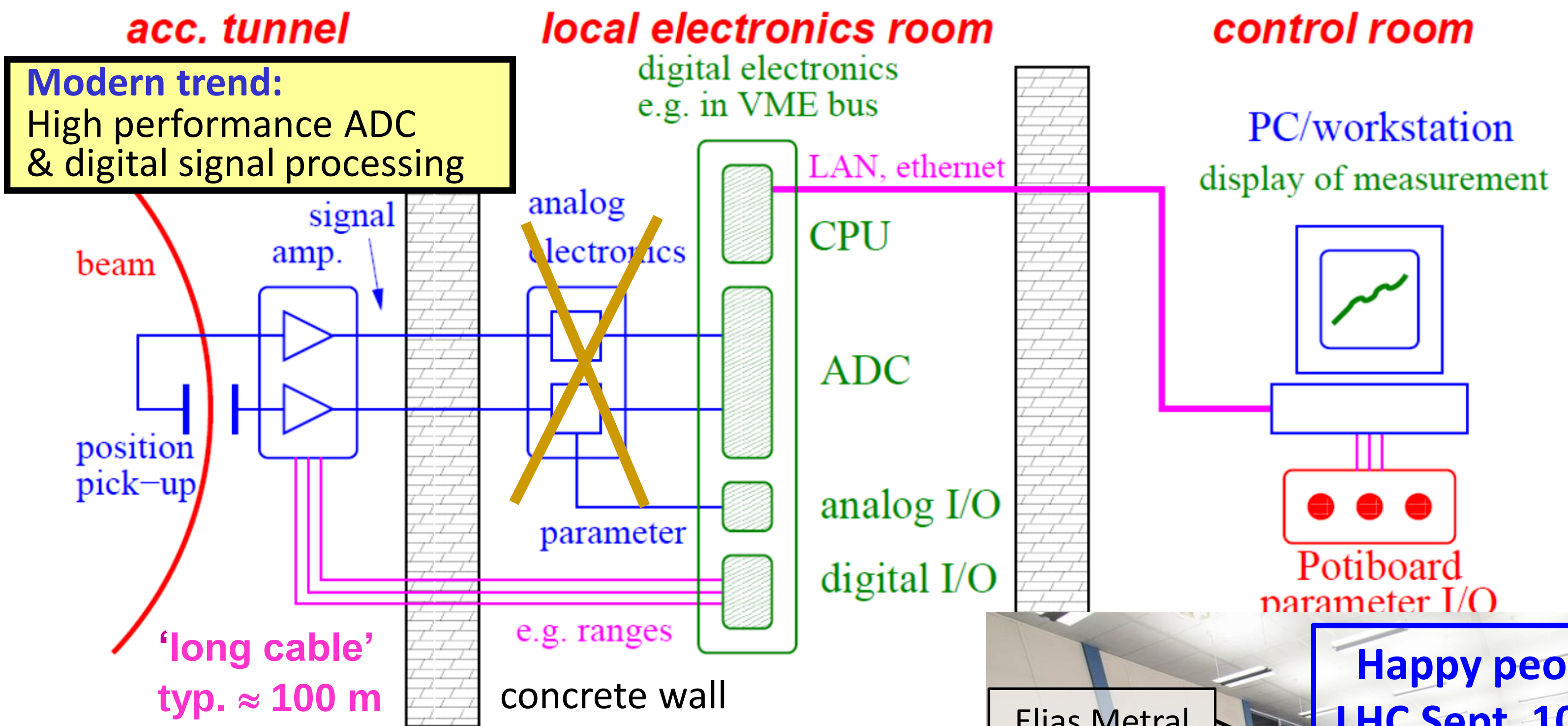
Typical Installation of a Beam Instrument

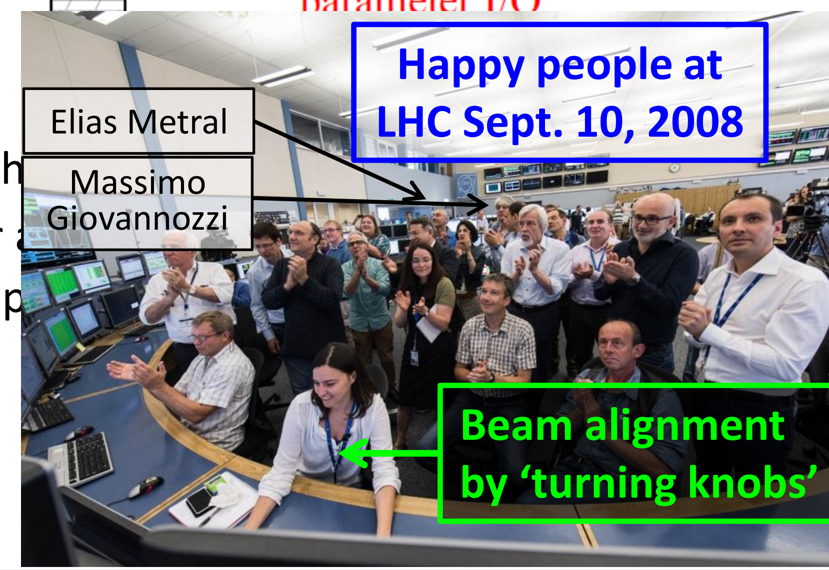


Accelerator tunnel:
- → action of the beam to the detector
- → low noise pre-amplifier and first signal shaping

Local electronics room:
- → analog treatment, partly combining other parameters
- → digitalization, data bus systems (GPIB, VME, cPCI, μTCA...)

Typical Installation of a Beam Instrument

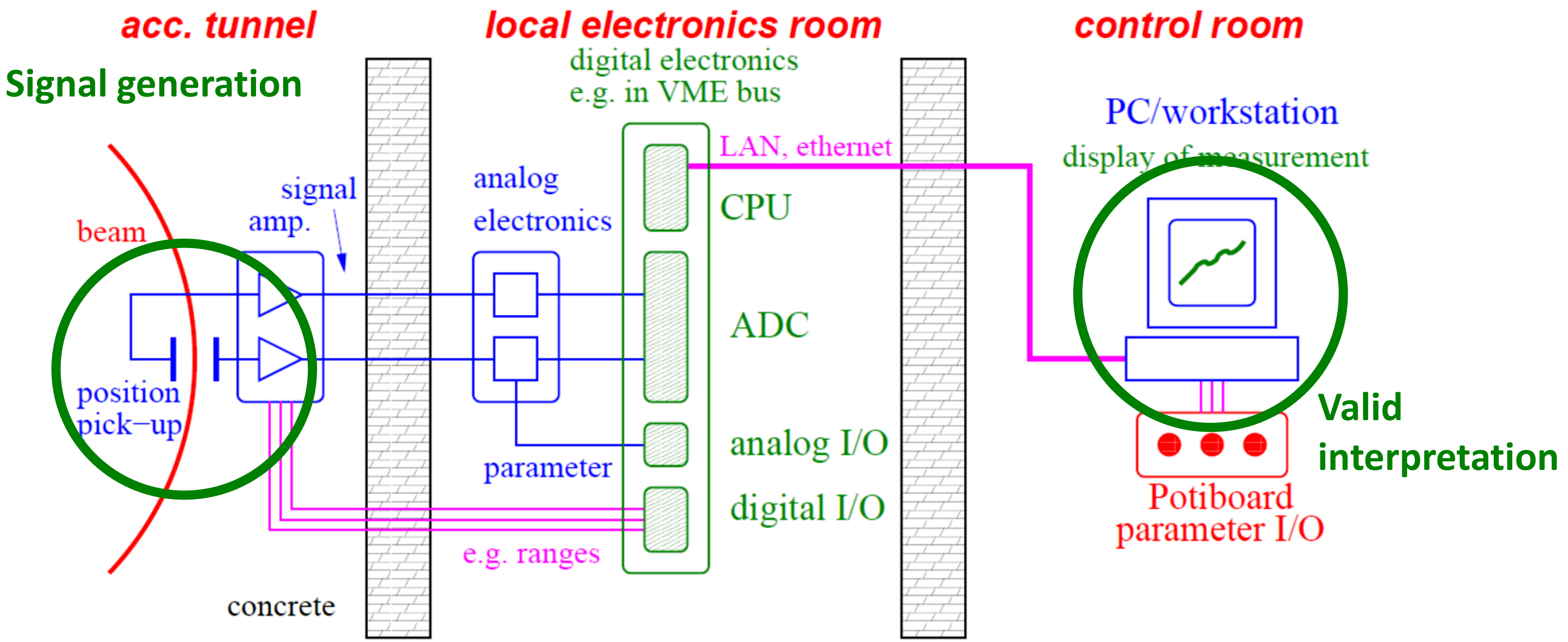




Accelerator tunnel:
- → action of the beam to th
- → low noise pre-amplifier a

Local electronics room:
- → analog treatment, p
- → digitalization, data

Control room:
- → visualization and storage
- → parameter setting



The goal of the lecture should be:

- **Understanding the signal generation of various device**
- **Showing examples for real beam behavior**
- **Enabling a correct interpretation of various measurements.**

Outline of the Lecture

The ordering of the subjects is oriented by the beam quantities:

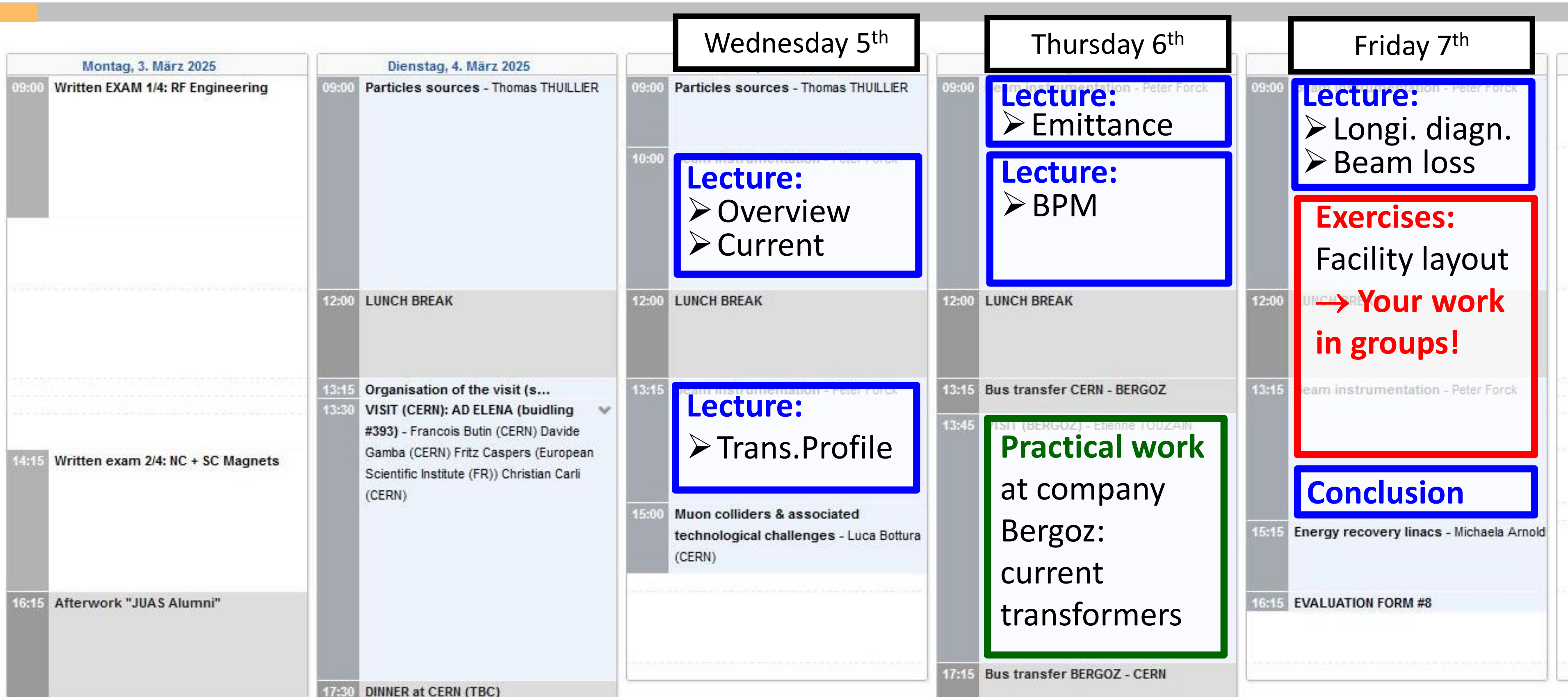
- **Current measurement:** Transformers, cups, particle detectors
- **Profile measurement:** Various methods depending on the beam properties
- **Transverse emittance measurement:** Destructive devices, determination by linear transformations
- **Beam Position Monitors for bunched beams**: Principle and realization of rf pick-ups, closed orbit and tune measurements
- **Measurement of longitudinal parameters:** Beam energy with pick-ups, time structure of bunches for low and high beam energies, longitudinal emittance
- **Beam loss detection:** Secondary particle detection for optimization and protection

It will be discussed: The action of the beam to the detector, the design of the devices, generated raw data, partly analog electronics, results of the measurements.

It will not be discussed: Detailed signal-to-noise calculations, analog electronics, digital electronics, data acquisition and analysis, online and offline software....

General: Standard methods and equipment for stable beams with moderate intensities.

Organization of the Lecture



Exercises: Facility layout at the end and quizzes during the lecture

Practical work: Organized by company Bergoz,
related to current measurement by current transformers

General: Please ask questions & make comments at any time
→ all interrupts are welcome!

Backup slides

Relevant physical Processes for Beam Diagnostics

Process	Physics	Technique	Examples
Electro-magnetic caused by moving charges	classical electro-dynamics	*U* & *I* measurement, low & high frequencies	Faraday cups, pick-ups, current transformers

Relevant physical Processes for Beam Diagnostics

Process	Physics	Technique	Examples
Electro-magnetic caused by moving charges	classical electro-dynamics	*U* & *I* measurement, low & high frequencies	Faraday cups, pick-ups, current transformers
Emission of photon by accelerated charges: (high relativistic e^- & p)	classical electro-dynamics	optical techniques (from visible to x-ray)	synchrotron radiation monitors
Interaction of particles with photons	atomic physics optics, lasers	optical techniques, particle detectors	laser scanners, bunch length measurement, polarimeters
Coulomb interaction of charged particles with matter	atomic and solid state physics	*U* & *I* measurement, optical techniques, particle detectors	scintillators, viewing screens, ionization chambers, ionization profile monitor
Nuclear- or elementary particle physics interactions	nuclear physics	particle detectors	beam loss monitors, polarimeters, luminosity monitors

Beam diagnostics deals with the full spectrum of physics and technology,
⇒ this calls for experts on all these fields and is a challenging task!

And, of course, accelerator physics for proper instrumentation layout.